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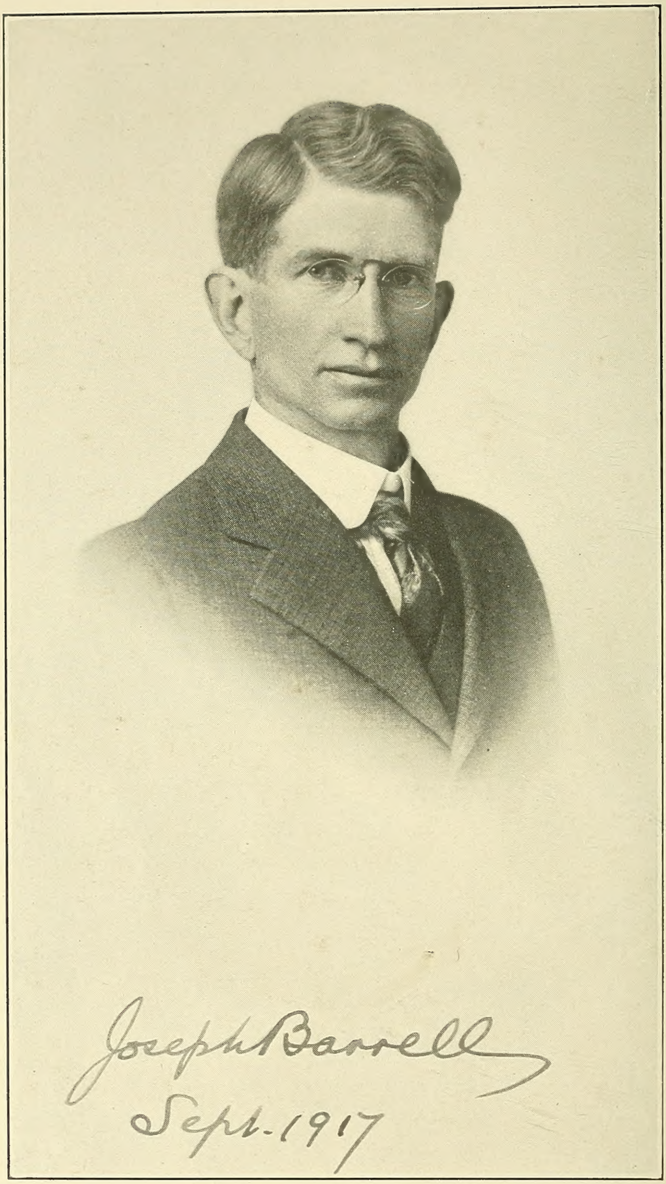
JOSEPH BARRELL

(1869 - 1919)

This notice was prepared by Professor Charles Schuchert, Yale University.


Joseph Barrell
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JOSEPH BARRELL.

(1869–1919)

In the passing of Joseph Barrell, American geology has lost a leader, and one who promised to stand as high as the highest. His period of preparation and of storing up fundamental experience was back of him, and had he lived twenty years longer, it seems clear that he would have become the chief exponent in the subjects of geologic sedimentation, metamorphism, the geologic bearings of isostasy, and the genesis of the earth. T. C. Chamberlin writes: "We had come to look upon him as one of the most promising leaders in the deeper problems of earth science," and R. S. Woodward adds that "Geophysics has suffered a great loss." John M. Clarke says: "I feel that the loss to geological science in this country at this critical time is very great." And in the opinion of W. M. Davis: "The tragic news of Barrell's death is a truly overwhelming disaster for American geology. We place him foremost in our science."

Professor Barrell's death is a severe blow to his colleagues at Yale, following so soon after that of Professor Irving. Coming to us as a young man, we have seen Barrell grow into a maturity that exceeded our hopes and more than justified our choice of him to fill the chair of structural geology at this University. He was a power among us, and it was around him that our graduate courses in geology were built. Personally we are bereft of a friend whose place can not be filled,—one whose simplicity of nature and strength of character were unique. His wonderful fund of knowledge was

always gladly placed at our disposal, and his constructive criticism and fertility of suggestion have been the stimulus to more of our work than we shall ever realize. We rejoice that the privilege was ours of working with him, and in our hearts there will always remain the grateful memory of his inspiring personality.

Barrell's death occurred in New Haven, Connecticut, on May 4, 1919, after a week's illness with pneumonia and spinal meningitis. He leaves a wife, Lena Hopper Bailey, and four sons, Joseph, Herbert Bailey, William Colburn, and Richard Lull. Standing 5 feet 10·5 inches in height, of the blue-eyed Nordic type, with a full head of wavy light-brown hair, he was spare of build and yet of great muscular strength, the "strong man" of his class at Lehigh. Once seen, he was easily remembered, and he was quickly picked out in a crowd. This was due in part to his tall slender build, his long and awkward stride, and his confident bearing, but more especially to the strength of character reflected in his large features, particularly the wide mouth and long, narrow nose concave in profile. He prided himself on the longevity of his ancestors, and believed he also would attain to great age.

Modest and optimistic, with a strong independence of mind, he prized true worth highly, and was easily aroused to point out shams and errors, as he does tellingly in his review of "The Place of Origin of the Moon," in "Schaeberle and Geological Climates," and more especially in "Fair Play and Toleration in Criticism." Simple in attire and fond of simple living, his intellectual ideals were of the highest, and it was his plan that his sons should have the best of collegiate training. An omnivorous reader and a hard worker, he never tired of unravelling the intricacies of earth structure. Yet with all his own work, he was always ready to help his colleagues and students, and those who had problems to solve found him ever fertile in suggestion. No man ever had better developed the power of detachment from his own views than did Barrell. He could examine his conclusions from all angles. As Davis says, "He interested himself in thinking about how he thought, and tried to evaluate the results of his thinking. He was as careful and critical in this respect as he was fertile and ingenious in mental inventions." His writings show

him to be a successful teacher, in that he prepares the reader for what is to come and then sets forth the processes and principles that underlie the results sought for. This is why most of his studies are detailed and lengthy.

Finally, Barrell was above all a staunch American and a believer in American science, as may be seen in his paper on "Sources and Tendencies in American Geology," in which he expresses the conviction that our country will continue the "place of world leadership in geologic science" which it has maintained since 1890.

The name Barrell, spelled in many ways, had its origin among the ancient land-holding knights of Normandy, and by them was introduced into England in 1066 at the time of the battle of Hastings and William the Conqueror. The Barrells used to be numerous throughout the south of England, but are now confined mostly to Suffolk and Herefordshire. The first American of the name was George Barrell, a cooper by trade, who arrived at Boston from St. Michaels, South Elmham, Suffolk, in 1637, and died there in 1643. He became a freeman of the Boston parish on May 10, 1643, and owned a house on what is now the southeast side of Hanover Street between Elm and Washington. It is interesting to note here that at this time Massachusetts Colony had a population of about 16,000. In November, 1638, George Barrell bought his home for £28, and soon added to it about a half acre of land for which he paid £3 more. At this time he was one of the 246 land-owners of Boston. He had but two sons, and one of them, John, also a cooper by trade, married Mary, daughter of William Colburn, one of the twelve original founders of the colony. It is from this union that have sprung all of the American Barrells of colonial origin.

Until recently, the Barrells were in the main sea-going people, ship-owners and merchants. The second John Barrell was a mariner, and we learn that his son John was a well-educated man and a successful shipping merchant. Professor Barrell in his genealogy says of John III: "The hazards of travel and of residence in tropical lands, however, told severely upon their number, so that notwithstanding several large families of sons, his descendants bearing the name have remained few in number and widely scattered."

The most widely known and wealthiest was Joseph Barrell of Boston (1739/40-1804), after whom the subject of our sketch, his great-grandson, was named. He married three times and had twenty children. This Joseph Barrell was an original thinker and a good speaker and writer. He is said to have "early espoused and firmly maintained the cause of his country," and for a time represented the town of Boston in the State Legislature. He lived well, and it was in his splendid home that General Washington was entertained during his visit to Boston. He was also one of the group of men who fitted out the ship "Columbia" and sent her into the Pacific, where in 1792 her crew discovered the Columbia River. Later they purchased of the Indians the territory about this stream, and in this way began the colonization of what has since grown to be the northern Pacific states of the American Union.

The father of Professor Barrell, Henry Ferdinand, was born in New York City, October 3, 1833. His son says he "grew up with a strongly developed taste for books, for nature, and for life in the country." Henry Ferdinand's father bought him a farm near Warwick, Orange County, New York, and it was here that he met Elizabeth Wisner, whom he married on April 15, 1858. The Wisners, originally from Switzerland, had been land holders for 150 years and officers in the colonial and later wars. In 1864, Henry Ferdinand sold this farm and bought another of seventy acres at New Providence, New Jersey, and here from 1875 to 1895 he was chairman of the trustees of the public schools in which the subject of this biography received his primary education. He was also interested in the public school library, which later became the town library. He had nine children, of which Joseph was the fifth child and the fourth son.

Joseph was born at New Providence on December 15, 1869. As a child, he was more interested in books on natural history, astronomy, and history, than in literature. His mother, now eighty-one years old, and after whom he takes, relates in a personal communication that "Joseph was always a good son and student, and a great reader. When but a lad he would get down a volume of the Encyclopedia Britannica and sit for hours reading it. Nothing distracted his attention. When he was tired

from sitting in one position, he would turn around, put his book on the chair, kneel down, and continue to read. When he was about ten years old, his father bought him a planisphere, and often at night he would take it and a book on astronomy, along with a lantern, and then lie on his back gazing at the stars and so learning their names with the use of the planisphere. Joseph attended the public school in New Providence until he was sixteen years old. The school combined grammar and high school studies, but very few scholars went further than the lower grades. He had two excellent principals, Mr. J. W. Kenneday and Mr. W. C. Armstrong, both college-bred men, and they took him through the higher studies necessary for college entrance. His elder brother Robert was then at Lehigh, and we could not afford the expense of two boys at college at the same time, so Joseph passed the examination for a teacher's certificate and taught a small school near home during the school year 1886-1887. His salary was $200, but as he boarded at home without charge, he saved that amount towards college expenses. The following year he attended Stevens Preparatory School at Hoboken, New Jersey, and won a scholarship for Stevens Institute, but preferred a college course at Lehigh University, which he began in September, 1888. In those days tuition was free at Lehigh, and Joseph probably did not receive more than $1,000 from home during the four years he was an undergraduate, the rest he earned. At home from boyhood he helped with the farm work during vacations. We had a sulky plow which he rode. He early became interested in geology, and when plowing would stop the horses and examine every peculiar stone turned up. His father was a naturalist and early interested his children in birds, moths, butterflies, plants, and in fact everything pertaining to nature."

As we have seen, Barrell took up collegiate work at Lehigh in 1888, and was graduated four years later with high honors. In 1893 he received from the same University the E.M. degree, in 1897 its M.S., and in 1916 its honorary degree of Doctor of Science. In conferring this last degree, President Drinker said: "Joseph Barrell.—Distinguished scientist, a recognized leader in the study and teaching of geology, known and honored for his research and writing in the science of the

earth in which the earth's history has been written by a mighty hand,—Lehigh is proud of the record of this alumnus whose lifework has been so modestly yet so ably done, and through whose work his Alma Mater has been highly honored."

In a sketch of himself written for the twenty-fifth anniversary of his class at Lehigh, Barrell says that in 1893, when he received his second degree, "jobs were rare and I regarded myself as lucky in securing an instructorship at Lehigh in mining and metallurgy." This position he held for four years, teaching mechanical drawing, mining and metallurgical design, making shop visits to various metallurgical plants, and practicing mine surveying with students in the anthracite mines. "Teaching is always better training for the teacher than for the taught. After the reorganization of the work in the first year I found some free time. The summers were put in in gaining experience, parts of the winters were employed in studying geology and practical astronomy, for which Lehigh gave me the degree of M.S. in 1897." His thesis for this degree is 419 pages long, and is entitled "The Geological History of the Archean Highlands of New Jersey, including their Extension in New York and Pennsylvania."

In 1898, Professor E. H. Williams, Jr., then of Lehigh, contemplating a division of his work, got the university to consent to hold vacant for two years the position of assistant professor of geology if Barrell would spend that time at Yale in advanced work. Barrell says this opportunity "was a most generous one on the part of Professor Williams. I spent the following two collegiate years at Yale and the summers working in Montana for the U. S. Geological Survey in general and mining geology. . . . In 1900 Yale gave me the degree of Ph.D., and thus a mining and metallurgical education, combined with a panic year on leaving college, had led logically into a career as a geologist. The initial engineering education and the experience of the eight years following 1892 formed the broad and solid base on which the following work has been built."

For three years after 1900, Barrell taught geology at Lehigh, with biology as a side issue. In December, 1902, he was married at Bethlehem, Pennsylvania, to Miss Bailey, and the three summer months of the year pre-

ceding were spent in Europe with Professors Herbert E. Gregory and Charles H. Warren, travelling "by foot, by bicycle, and by third-class trains, the object being to see the countries and study geology rather than to do sightseeing in the cities. . . . Another turn in the wheel of fate called me in 1903 to Yale." In 1908 he was promoted to a professorship and, as he says, was "fixed as a staid professor. The position offers opportunity for three kinds of work, one-third of the time teaching geology to undergraduates in Yale College, one-third teaching in the Graduate School future professional geologists, and one-third of the year for research. The latter gives the most visible measure of work accomplished."

Barrell was a member of the Sigma Xi honorary scientific society, and president of the Yale Chapter in 1911-1912. He was also elected to the Phi Beta Kappa chapter of the same University. He was a fellow of the Geological Society of America, the Paleontological Society, and the American Association for the Advancement of Science, and a member of the American Academy of Arts and Sciences. Only a few days before his death, there came to him the news of the highest honor that can be given to an American scientist, election to the National Academy of Sciences.

A man of science, and especially one deeply interested in generalizations, should be endowed with imagination under restraint. Barrell had a great deal of this quality, and loved to speculate under the limitations of "multiple hypotheses." It was a pleasure to listen to him telling his children about gnomes and elves, and occasionally, as in his "Central Connecticut in the Geologic Past," or "A Vision of Yale in 6010," he allowed himself flights of figurative writing." The most humorous of these only too rare instances appears in a discussion of a classification of marine deposits in the *Bulletin* of the Geological Society of America. Here he is presenting the view that materials foreign to the sea may be rafted there by trees and ice. And then he digresses into this: Man has become "an important geological agent. The oxidized and inorganic débris which he throws overboard from ships must already mark out the steamer lanes, especially, across the abyssal ocean bottoms. The unalterable materials which he con-

tributes most abundantly to the deposits of the sea are coal ashes, broken dishes, and bottles. These are being permanently incorporated in the crust. . . . The name being recorded most widely and indelibly on the earth at the present time is the name of him who made Milwaukee famous."

As a teacher, Barrell was by far the most effective with graduate students and geologists. The former were enthusiastic in their praises of their instructor in dynamical and structural geology, for he gave them much that was not to be found in books. He succeeded well with the undergraduates, but many of them found him exacting in detail, and some would say that he was "too statistical," referring to the detail that the first-year man in college geology does not properly appreciate. On the other hand, one of his graduate students, Carl O. Dunbar, writes: "I shall prize even more than ever those golden days when I sat before him watching the twinkle in his eyes that so often foreshadowed a brilliant thought that was taking shape behind them. His image will always be my conception of the thinker." Another, Walter A. Bell, says: "There was our admiration and appreciation of his keen analytical mind which was balanced on the other hand by the breadth of his judgment and the depth of his fertile imagination. But there was more than this—a more elusive personal charm that bound us to him. He stimulated the mind as cool mountain breezes and mountain heights stimulate the senses. You rarely sensed this in his writings, but always in conversation, in the class room, or wherever you came into personal touch with his intellectual vitality."

As a lecturer, Barrell was often called on by universities other than Yale. In 1912 he gave a series of five lectures at the University of Illinois, dealing with "The Bearing of Geology on Man's Place in Nature," and "The Measurements of Geologic Time." In 1914 he gave a course of three Sigma Xi lectures at the Universities of Missouri and Kansas. At Columbia he gave two years later six lectures on isostasy, and at New Haven he presented before both the Sigma Xi and Phi Beta Kappa societies his interesting talk on "The Habitability of Worlds."

As a geologic expert, Barrell testified in a number

of lawsuits, the chief ones being in relation to the Utah Apex Mining Company of Bingham, Utah, the Federal Mining and Smelting Company of Shoshone County, Idaho, and the Hudson Blue Stone Company of Kingston, New York. He made a good witness, not only because of his extensive knowledge of mining and geology, but more especially because his testimony on the stand could not be shaken by opposing counsel.

An analysis of Barrell's writings shows that he progressed from simpler field relations to the most complex of geologic problems. It is also clear that his best results were obtained through generalizing from the publications of others. He loved to assemble the field and laboratory observations made by other workers in comparison with his own, and then, subjecting them to the test of multiple hypotheses, ascertain the probable explanation of the facts under study.

Barrell's first publications, in 1899 and 1900, deal with mining, but since 1901 nearly all of them have had to do with geology. His bibliography, if completed in detail, would take note of about 150 notices and reviews of books, nearly all of which appeared in this Journal. Of these nineteen contain original matter, and are therefore included in the bibliography. Nearly all deal with isostasy, the origin of the earth, and metamorphism, subjects most familiar to Barrell. When he set himself to write a review of a book, he produced a lucid analysis, with discussions of the conclusion attained by the author. Of short papers and longer memoirs, there are fifty-one, totalling nearly 1,700 pages. In addition, there are eight manuscripts in a more or less finished condition, and some of these, after they have been edited by his colleagues, will probably be printed within a year.

Barrell's earliest papers, as has been said, relate to mine surveys. Then he took up areal geology, studies of the relations of intrusive masses, and their alteration and mineralization of the invaded geologic formations. After some years as an instructor of graduate students in dynamic geology, his ideas in regard to processes of erosion, sedimentation, the formation of deltas, and the discerning of ancient climates in the sediments took form, and it is on these subjects that he next wrote. Nearly one-fourth of his publications fol-

low these lines. He also did much to build up the science of paleoclimatology, and in paleogeography he established principles for discerning the shore-lines of the seas and the extent and elevation of the ancient lands that were furnishing the sediments. Had he lived longer, he would have done much more, and an unusual opportunity for stimulating others would have come to him as chairman of the new Committee on Sedimentation in the National Research Council.

Probably Barrell's most philosophic and most difficult work relates to isostasy. About one-sixth of his publications have to do with the strength of the earth's crust. He states that "The larger features of the earth's surface are sustained in solid flotation," and "the subcrustal shell is subjected to but little else than hydrostatic pressure." Isostatic balance is, however, not everywhere in adjustment, for "the outer crust is very strong, capable of supporting individual mountains, limited mountain ranges, and erosion features of corresponding magnitude."

The length of geologic time was another problem that deeply interested Barrell. In his "Rhythms and the Measurements of Geologic Time," he came to the conclusion that through the rhythmic oscillations of the terrestrial processes which the earth has undergone, its age is many times greater than even geologists in general have imagined—in fact, that it is of the order of about 1,500 million years.

Another line of research which occupied Barrell was the origin and genesis of the earth, and here he extended in modified form the Chamberlin-Moulton planetesimal hypothesis, i. e., that the planets and their moons arose out of the sun during a time of induced tidal disruption. Some of his best work was to develop along this line.

While an undergraduate student at Lehigh, he became interested in the physiography of the highlands of New Jersey and Pennsylvania. He had studied Davis's works, but on account of the peculiarities of the rivers that flow through the ridges and the many wind-gaps in the region with which he was familiar, he concluded that much of the area must have been beneath the sea and been covered by sedimentary deposits. This was in opposition to the prevalent view that the present rivers were incised in the "Cretaceous peneplain."

His views were formulated for the first time in his Lehigh thesis of 1897, but it was not until 1913 that he presented the matter in more mature form before the Geological Society of America. The supposed Mesozoic peneplain of southern New England was in reality, he said, "stairlike or terraced in its character, facing the sea," and of marine origin. It was this study that was absorbing him most in recent years, and his *magnum opus* on it was to appear a few years hence. There is a manuscript dealing with it, but this represents only a small part of what the final publication was intended to be.

As Barrell also taught biology at Lehigh and historical geology at Yale, it was natural that he should be interested in paleontology. This side of his activity is little known away from Yale, but his colleagues there knew of his deep interest and knowledge in this line. Animal structures interested him as mechanisms, and he tried to see the operation of the laws of mechanics in them. And through his insight into paleoclimatology he tried to discern the operation of the changing environment as the most important cause of organic evolution.

Finally, in one of his last papers, "Sources and Tendencies in American Geology," he states that "geologic research in the past generation has been passing out of the qualitative stage and has partaken notably of the quantitative character." In this great advance he names Dana, Hall, Marsh, Cope, Powell, Dutton, Gilbert, Davis, Chamberlin, Van Hise, and Irving as those who will stand out as the great leaders of the earth sciences in America.

Review of the Writings of Joseph Barrell.

Mining Engineering.

Barrell's first experience as a mining engineer was in 1894, while with the engineering corps of the Lehigh Valley Coal Company, at Wilkesbarre, Pennsylvania. In June, 1897, he joined the engineering corps of the Butte & Boston Mining Company of Butte, Montana, and worked with them and the Boston & Montana Company for over a year. Of this work he says: "The initial wages of three dollars a day seemed a recogni-

tion of some degree of ability until I learned that I was indebted to the miners' union which fixed the minimum wage for laborers underground at that figure. The work was interesting and involved difficult problems in the plumbing of crooked shafts, and the measurements of amounts of ore extracted from old workings.'' These experiences led to his publishing in *Mines and Minerals* during 1899 and 1900 a series of five papers which he wrote while at Yale studying for the doctor's degree. They have to do with the methods and errors of mine surveying, instrumental errors, methods of keeping stope books, and the choice of survey instruments. The papers abound in mathematics and in diagrams, and thus foreshadow two of Barrell's future tendencies in geology.

Regional Geology and Metamorphism.

During the summer months of 1899, Barrell was field assistant to W. H. Weed of the U. S. Geological Survey, mapping the ore-bearing formations of the Elkhorn Mining district of Montana. This work, Barrell states, was done alone, much of it on horseback, in the mountainous region between Butte and Helena. It involved a study of the great successive intrusions of molten rock which in the early Tertiary had broken up the crust, and brought in the wealth of gold, silver, and copper. The first result of these field studies was the publication of the ''Geology and Ore Deposits of the Elkhorn Mining District,'' by W. H. Weed, with an ''Appendix on the Microscopical Petrography of the District,'' by Joseph Barrell.

Having done this field work, Barrell returned to Yale in the autumn of 1899 and made his results the basis of a dissertation for the doctorate. With the guidance of Professor L. V. Pirsson, he made an elaborate petrographic study of the rocks, and these results, along with the geology of the Elkhorn area, formed the basis of his dissertation, which is entitled ''The Geology of the Elkhorn Mining District.''

As a result of the Elkhorn work, Barrell in his dissertation wrote a chapter on ''The Physical Effects of Contact Metamorphism.'' This is also the title of an article published in this Journal in 1902, and abstracted from the chapter referred to. In this paper Barrell

discusses the changes of mass and volume through metamorphism, and states, among other things, that the shrinkage in rock of certain compositions may be "from 25 to 50 per cent in volume, attended with the evolution of great quantities of gases which at surface pressures and temperatures would amount to several hundred times the volume of the original sediments."

Metamorphism always remained one of Barrell's foremost lines of work, and as late as 1914 he wrote a manuscript entitled "Relations of Subjacent Igneous Invasions to Regional Metamorphism." It is hoped that this paper may be printed in 1920.

In the summer of 1900, Barrell was again employed by the U. S. Geological Survey in a two months' reconnaissance of the surface geology of the Deerlodge region of Montana and of the underground geology of Butte. The next year he began, again under the direction of Mr. Weed, a three months' geological survey of the surface and underground geology of the Marysville mining district, Montana. His results were worked out at Yale and published as "Geology of the Marysville Mining District, Montana: a Study of Igneous Intrusions and Contact Metamorphism." This region was one of the noted gold-producing centers of Montana, and the mines were situated around the margins of the irregular Marysville bathylith of quartz diorite, whose surface exposure is from half a mile to one and a half miles broad and two and one-half miles long. This invasion of igneous rock was primarily the cause of the location of the mineral wealth in this district. It is "but 6 miles at its nearest point from the exposed surface of the far greater Boulder bathylith, a granitic mass which is petrographically a quartz monzonite in normal composition. The Boulder bathylith possesses a general rudely rectangular form, occupying about 60 miles in latitude by about 35 in longitude, and holds within its confines the mining city of Butte, from which for many years past has poured a flood of silver and a quarter of the world's production of copper. Other smaller mining centers also lie within this large granitic area, while such important ore deposits as those of Elkhorn and Unionville, south of Helena, have been found about its margin."

In regard to the Marysville report, which has now

become one of the classics in geology, Pirsson says of it in this Journal: "The special character of the work lies in the detailed investigation of the bathylithic body, of the method of its intrusion, of its form, and of its relations to the surrounding rock masses both past and present." The intrusion Barrell could not explain by the accepted methods, and did so by a new theory, that of magmatic stoping. Daly, in his book "Igneous Rocks and their Origin," states that "It was in the Cordilleran region, at Marysville, Montana, that Barrell independently invented the stoping theory of magmatic emplacement."

Because of the large scale on which the Marysville and Boulder bathyliths are exposed, and because of the forceful presentation of the field relations and the clearness of Barrell's inferences therefrom, Suess in his great work, "The Face of the Earth," was led to say that the Marysville report is "one of the most instructive works produced in modern times" connecting granitic invasions with volcanoes.

The interesting and popularly written pamphlet, "Central Connecticut in the Geologic Past," visualizes the major events in the geologic history of the state. It is illustrated by a series of eight highly instructive structure sections drawn by Barrell himself. These sections show clearly Barrell's faculty for picturing his thoughts; not infrequently he would express an idea in graphic form before he put it in writing.

Erosion, Sedimentation, and Climatology.

The writer of this biography joined the Geological Department of Yale University in 1904, and at that time became acquainted with Barrell, then an assistant professor. As both of us had our offices in the Peabody Museum, we saw much of each other, and often our discussions had to do with sedimentation. I would relate to him the varied phenomena which I had seen in the field and the distribution of the formations, and he would try to decipher their processes of accumulation. Then in 1905, after I had listened to his course of about twelve lectures, I urged him to publish his views, especially as to the depth of water and the climate suggested by the nature of the sediments. In the following year he

published a series of three papers on the "Relative Geological Importance of Continental, Littoral and Marine Sedimentation" in the *Journal of Geology.*

In these papers he sets forth a quantitative view as to the relative importance geologically of these three types of sediments, and the criteria for separating them. It is a study of facts already assembled in the geologic literature, but always from their original sources. Further, it is the application of changing and cyclic geographies in their relation to stratigraphy, with the emphasis on the fact that by no means all of the sediments are of marine origin. Among other things he develops the criteria for discerning subaërial delta deposits, and he shows that such deposits attain their greatest development after epochs of mountain-making unaccompanied by notable uplift of the continental platforms. He also emphasizes the cyclic relations between continental and marine sedimentation in geologic history. The wide and cyclic significance of mud-cracks in association with other features indicating flood-plain deposits is discussed at length and applied to the interpretation of Proterozoic deposits in Montana and the Grand Canyon of the Colorado.

The significance of desert deposits becomes very striking when one notes that one-fifth of the present land surface is desert tracts. And Barrell estimates that the subaërial deposits of piedmont waste, of continental basins, and of deltas cover about one-tenth of the emerged continental surfaces. Adding these "to the estimate of the deposits of arid climates would give a fifth of the land surface as mantled by continental formations." The lands in the course of the geological ages are, however, warped and elevated into mountain ranges, so that the geological record "should show a far less proportion of these and superficial land deposits." On the other hand, basin and delta deposits should be quantitatively as great as those laid down upon the floor of the epeiric seas.

Having developed the principles of sedimentation for continental and shallow-water marine deposits, Barrell applies them in 1907 to a late Mississippian formation in the paper "Origin and Significance of the Mauch Chunk Shale." Here are presented the significant facts regarding this formation, gathered from the literature

and from personal observation. He concludes that "In the anthracite region, more surely in the southeastern and eastern portions, the whole formation [which is about 3,000 feet thick], from top to bottom, was a subaërial [delta] deposit laid down under a semiarid climate." The nearest approach to-day to a similar area is that of the highly arid Punjab region near the base of the Himalayas, and of the lower plains of the Indus River. "These comparisons, while not intended to convey the idea that the Appalachians were ever of Himalayan magnitude, are suggestive of a more massive range of mountains and a wider land area to the eastward of the Pennsylvanian geosyncline than is customarily thought of as existing in Upper Devonian and Carboniferous times."

Having seen much of the Carboniferous of eastern Pennsylvania, Barrell had asked himself, "To what extent have the tectonic movements and climatic variations caused the great contrasts seen here in the Lower and Upper Carboniferous formations?" To solve this problem, he took up in detail the principles that have to do with the relations between modern climate and terrestrial deposits, and published his conclusions in "Relations between Climate and Terrestrial Deposits." He writes: "The environment of the lands may be classified into three fundamental and independent factors—the relations to the surrounding seas, the topography which forms their surfaces, and the climates which envelope them; each of major importance in controlling the character of the lands." Fundamental are the relations of continental fluviatile deposits to the climates, and they may be successfully used in determining those of the geologic past. "This is exclusive of the significance of salt and gypsum deposits on the one hand or of glacial deposits on the other, which are of course universally recognized, but these are the marks of climatic extremes."

The first part of the paper under review has to do with the relations of sediments to regions of erosion. It deals with the relation of physiography to erosion and the consequent supply of waste as sediments to the formations. Then he takes up the relations of sediments to regions of deposition, and finally the relations of climate to fluviatile transportation. These parts

lead to the conclusion that "Climate is a factor comparable to disturbances of the crust or movements of the shore-line in determining the nature and the variations in the stratified rocks of continental or offshore origin, thus playing a part of large, though but little appreciated, importance in the making of the stratigraphical record."

Along with many other things, Barrell finds that "While the varying powers of erosion and transportation are delicate stratigraphic indicators of *climatic fluctuations,* the chemical and organic control accompanying the deposition are the more secure indicators of the *average climatic conditions.*"

Finally, what was the origin, environment, and significance of the conglomerate and sandstone formations intercalated between others of different nature? His answer is that these coarse materials have three origins: First, marine conglomerates and sandstones; second, tectonic conglomerates and sandstones; third, climatic conglomerates and sandstones.

"Changes in volume of ocean waters, earth movements, and atmospheric activities are the three mixed and fundamental causes by which the three classes of deposits become possible, but the records which they embody are largely distinct and independent. By separating conglomerates and sandstones into these three classes, the sedimentary rocks, therefore, present a threefold record, the marine conglomerates giving that of the variable relations of land and sea; the tectonic conglomerates, the record of variable vertical uplifts; the climatic conglomerates, the record of variable temperature and rainfall."

Barrell next took up for study "Some Distinctions between Marine and Terrestrial Conglomerates," the gist of which he presented before the Geological Society of America in 1908. Of this study there is printed only a half-page abstract, but back of it lies over 200 pages of manuscript completely rewritten in August, 1910, and entitled "Marine and Terrestrial Conglomerates." It is hoped that this paper may be printed before the close of 1920. In the abstract he states that "The truly terrestrial forces produce vastly more gravel, spread it far more widely, and provide more opportunities for deposition than do the forces of the littoral zone."

Marine conglomerates are "limited to considerably less than 100 feet in thickness," while terrestrial ones are "frequently measured in hundreds and occasionally in thousands of feet."

Having finished the paper on conglomerates, Barrell now sought out a thick and unfossiliferous conglomerate-sandstone series whose age relations were obscure. Such a series he found in the southern Appalachians, and upon this he made another study that remains unpublished. The conglomerates, sandstones, and slates of the Ocoee and Chilhowie groups of Tennessee, North Carolina, and Alabama, have long been a stumbling block in classification, because it is only near the top of the long series that fossils have been found. On the basis of these fossils, Keith finally referred all of the Ocoee and Chilhowie to the Lower Cambrian. Barrell discusses the many formations of this series, aggregating between 9,000 and 13,000 feet in depth, and concludes that the lower part, with a maximum thickness of 7,500 feet, is of terrestrial origin. The middle formations, with a thickness of 3,400 feet, are at least in part a terrestrial deposit, though a part is probably marine. The remaining 2,700 feet are entirely of marine origin.

In 1912, Barrell, in continuation of his studies of sedimentary formations, published the paper entitled "Criteria for the Recognition of Ancient Delta Deposits." He defines a delta "as a deposit partly subaërial built by a river into or against a body of permanent water." This study concerns the detailed structures of deltas and the physiography of the land that furnished the detritus. It is a difficult study because of the great variability in the extent of deltas, the marked variation in the character of their sediments, the size and streaming power of the river or rivers that bring the material, and finally the wide variation in the wave and streaming forces of the water body and the depth of the water in which and in front of which the deltas are laid down.

The underlying principle of this work is the cyclic one. The erosion by rivers "passes through its cycle of youth, maturity, and age, and the characteristics of the river valley and river waste change with the distance from the headwaters and with the progress of the erosion cycle. There must also be a delta cycle, and it

is to be expected that the size of the delta and the character of its deposits will depend not only on the original relation of the other physiographic elements of the continent, but on the progress of the cycle of erosion on the one hand and of the cycle of deposition on the other.''

In 1913-1914 followed the application of the criteria of the previous paper to an ancient or fossil delta in the study entitled ''The Upper Devonian Delta of the Appalachian Geosyncline.'' This is one of Barrell's best pieces of work, and a very philosophic one, for it brings out the relations of the Appalachian delta, both to the interior sea and to the extensive eastern land Appalachia and the Atlantic Ocean beyond. This extensive delta system began to form in the Middle Devonian and ceased in early Mississippian time. Its sedimentary volume Barrell computes at about 16,500 cubic miles for the Middle Devonian and 63,000 cubic miles for Upper Devonian time. ''This is an impressive measure of the volume of the adjacent land which was eroded in Upper Devonian times. But it is a minimum measure, since that part of the rocks which was taken into solution was carried farther away, and of the mechanical sediments it represents only that part which was carried westward into the trap of the geosyncline.''

This great amount of Upper Devonian sediments implies a much greater Appalachia than is usually assumed. In elevation it must have exceeded the present Sierra Nevadas. Barrell states that this old land ''was not confined to the limits of the present continental shelf. . . . The foundations of Appalachia are buried some thousands of feet beneath it, extend beyond it, and doubtless slope gradually for an unknown distance toward and beneath the basin of the Atlantic,'' where is now deep ocean. ''In Upper Devonian times the mountains which rose above these foundations stood on the eastern side of the Appalachian system.'' Accordingly, great parts of eastern Appalachia have been fragmented and sunk into the depths of the Atlantic during Mesozoic time.

As early as 1905, Barrell began to ask himself, ''What were the geographic and climatic conditions which controlled the nature of the Old Red Sandstone deposits?'' In 1907 he wrote out his views but withheld them from

printing, thinking that he and the present writer would find means of visiting Scotland. As this opportunity did not come, he presented his views in 1916 in the paper "Dominantly Fluviatile Origin under Seasonal Rainfall of the Old Red Sandstone." A copy of this was sent to Professor T. G. Bonney of University College, Cambridge, England, and his letter of thanks to Barrell opened with the word "Eureka." Truly we have here the correct explanation of the origin of the Old Red Sandstone.

"The central conclusion reached in this paper is that the Old Red Sandstone formations were not deposited in lakes and estuaries, nor are they of desert origin." They are "river deposits accumulated in intermontane basins," "exposed to air in times of drought," and "similar to the basin deposits of the western United States laid down in the Tertiary period between the growing ranges of the Cordillera." "The Great Valley of California may therefore in the present epoch, both in physiography and in climate, be cited as a striking illustration of the nature of the Old Red Sandstone basins."

Physiography.

Previous to 1908, most physiographers held that the flat sky-line of the land seen in the southern part of the New England states represented a Cretaceous peneplain uplifted in early Tertiary time, but in 1912 Barrell put forward a view long entertained by him, namely, that not only was this plain not of Cretaceous age, nor even of subaërial erosion, but rather that the supposed plain is a series of seven sea-cut terraces, the result of wave planation, made at different times during the late Mesozoic and Cenozoic eras. This fundamental change in interpretation was presented before the Geological Society of America in 1912 under the two titles "Piedmont Terraces of the northern Appalachians and their Mode of Origin," and "Post-Jurassic History of the Northern Appalachians." Since then from time to time Barrell had been working on this alternating series of uplifts and strand-lines, and most of the time in the laboratory with topographic maps. On October 16, 1915, he guided the New England Intercollegiate Geological Excursion across four of these terraces, made since Mio-

cene time, from New Haven northwest to Litchfield, a distance of about 35 miles. It was a memorable and proud day for the writer to see Professor Barrell presenting his views and defending them against all comers before a more or less dissenting audience, among which were W. M. Davis, R. A. Daly, W. W. Atwood, and D. W. Johnson. If these gentlemen were not at that time convinced, they were at least unable to make headway against the leader of the party.

It was Barrell's intention to spend some of the summer of 1919 and most of that of 1920 in the field to try out in critical places between Virginia on the south and Rhode Island on the northeast what he had observed first about Lehigh and later in Connecticut. This plan is now broken, but he has left a long manuscript treating of these terraces, and a great mass of annotated folios and generalized drawings showing the various facets in their present eroded condition. This manuscript is now being edited by H. H. Robinson, and will be published in the course of the year.

Rhythms and Geologic Time.

Barrell was one of the participants in a symposium on the interpretation of sedimentary rocks at the Albany meeting of the Geological Society of America in 1916. Here he presented a part, but only the smallest part, of a study on "Rhythms and the Measurements of Geologic Time." This is his most important study, and will long remain a source of information and stimulation to research along several lines of philosophical thought.

He had long been attracted by the cycles of sedimentation, and now he states that "Nature vibrates with rhythms, climatic and diastrophic." The viewpoint of the six parts of the study is geological, though the evidence furnished by radio-activity is thoroughly reviewed. Part I treats of the rhythms in denudation, and shows that "erosion is essentially a pulsatory process," and that "a single rhythm is the erosion cycle; and small partial cycles are superimposed on larger." Here then is developed the hypothesis of compound rhythms. This part leads to the conclusion that the present rate of denudation is high, and "very much greater than the mean of geologic time." Part II deals with rhythms

in sedimentation, and shows that sedimentation is "not a continuous process, even during a stage of crustal depression." Therefore the stratigraphic record is replete with "breaks" of varying time lengths, the non-seeable greater disconformities and the lesser but more numerous diastems.

Part III treats of the estimates of time based on geologic processes, on erosion, sedimentation, hypothesis of compound rhythms, amount of oceanic salt, and on the loss of primal heat. In this presentation we get a more adequate idea of the quantitative lengthening of geologic time. "Measurements of time based on radioactivity" is the subject of Part IV, which is a worthy associate of A. Holmes's "Radioactivity and the Measurement of Geological Time," published in 1915. Finally, in Part VI, "Convergence of Evidence on Geologic Time and its Bearings," the geological and physical arguments are bound together into a unity, resulting in the conclusion that at least 550 million, and a maximum of 700 million years have elapsed since the beginning of the Cambrian. This is, moreover, less than one-half of geologic time, for the Laurentian or post-Ladogian granites, the oldest great invasions of igneous magmas into vast thicknesses of sedimentary formations, have an age as great as 1,400 million years. The earth is, therefore, much older than even this great figure.

Harlow Shapley, the astronomer, accepts Barrell's geologic time estimates, and says: "We may study the stars, indeed, with the aid of fossils in terrestrial rocks, and acquire knowledge of atomic structure from the climates of Precambrian times." "In the growth of our concepts of the age of the earth, Barrell's discussion is likely to mark an epoch because of its consistent carefulness, its great expansion of geologic time beyond the commonly accepted limits, and its decided rebellion against the stringent limitations set by Kelvin and later physicists."

Isostasy.

It is interesting to note Barrell's early independence of mind and his love for quantitative studies and philosophical analyses in geology, as shown in his notice in this Journal in 1904 of T. M. Reade's "Evolution of Earth Structure." In August, 1906, he notices, also in

this Journal, J. F. Hayford's paper, "The Geodetic Evidence of Isostasy," and gives a brief historical review of the place of this subject in geological literature and of the problems upon which it bears.

In 1914, Barrell was led to study the theories leading to the conclusion that the poles of the earth are not fixed. Astronomers and some geologists are opposed to the theory of polar wanderings, but students of ancient climates and of the geographical distribution of floras and faunas have been adherents to this view. In his "Status of Hypotheses of Polar Wanderings," Barrell states: "From these considerations it is seen that closer examination tends to cut down more and more even those moderate limits of polar migration set by [the mathematician] Darwin. It would appear that the assumption of polar wandering as a cause of climatic change and organic migrations is as gratuitous as an assumption of a changing earth orbit in defiance of the laws of celestial mechanics."

During the years 1914 and 1915, Barrell published in the *Journal of Geology* a series of eight papers that were later collected and bound in one volume under the title "The Strength of the Earth's Crust." This work at once placed him high among the geodesists. Arthur Holmes writes of it as a "remarkable series of papers, which is worthy of the most careful study," and "constitutes a valuable and stimulating contribution to terrestrial dynamics." L. V. Pirsson says: "They constitute probably the most serious and profound discussion, which has yet been attempted, of the facts which are known and of the theories which have been deduced from them, concerning the strength of the earth's outer shell."

The first part of this series of articles treats of the geologic tests of the limits of strength. In Parts II and III is discussed the "Regional Distribution and Influence of Variable Rate of Isostatic Compensation." Part IV deals with the "Heterogeneity and Rigidity of the Crust as Measured by Departures from Isostasy," while Part V is on the "Depth of Masses producing Gravity Anomalies and Deflection Residuals." Part VI is devoted to the "Relations of Isostatic Movements to a Sphere of Weakness—the Asthenosphere," and Part VII to "Variation of Strength with Depth, as Shown

by the Nature of Departures from Isostasy." The final part has to do with the "Physical Conditions Controlling the Nature of the Lithosphere and Asthenosphere." It is evident that Barrell intended to publish other parts in this series, for we have found among his papers the manuscript for Part IX on the "Problems involved in the Temperature Gradient conforming to the Curve of Crustal Strength." During the winter of 1914-1915 he wrote still another manuscript that appears also to have been intended for this series; it is entitled "Relations of Pleistocene Warping to Strength of Crust." These two articles we have been advised not to publish in their present form; they will, however, be of service to the Geological Department of Yale University.

Pirsson says of these papers: Barrell "finds that the crust is very strong when measured by its capacity to support great deltas, mountain ranges or large internal loads due to variations in density not in accord with topography, while on the other hand the altitudes of the continents as a whole or in large sections show nearly perfect isostasy. The maintenance of such isostatic conditions through geologic time, in spite of opposing geologic activities, is held to imply the existence of a zone of undertow below the zone of compensation, which is both thick and weak to shearing stresses. Geologically, such a zone, called the asthenosphere—the shell of weakness—must have important bearings, which are treated in the later portions of the work."

With this biography are printed two other papers on isostasy written by Barrell for this Journal, the longer one having been completed shortly before his death. This paper was written in answer to certain recent adverse criticism of the theory. Here Barrell gives an easily readable outline of the theory of isostasy, a long presentation of the problems connected with it, and his final interpretation of the isostatic data of India, the birthplace of the hypothesis.

Genesis of the Earth.

In 1907, Barrell was aroused into criticism by Professor W. H. Pickering's paper, "The Place of Origin of the Moon." This place the latter thought to be the Pacific Ocean, thus giving rise to that basin, an hypoth-

esis first stated, but cautiously, by Osmund Fisher in 1882. Barrell quickly demonstrated that oceanic basins could not have arisen in this way.

Barrell left a long manuscript on the genesis of the earth that it is hoped may be published in book form along with some of his other geologic essays. As an instructor of historical geology, and because of questionings by the writer of this biography, but more especially through the writings of Chamberlin, he was gradually led to delve more and more deeply into this subject. Then in 1916 appeared Chamberlin's book, "The Origin of the Earth," a work "which has long been desired by geologists as well as other scientists," and as Barrell wrote a critical review of it in *Science,* those who wish may obtain from this review some of the points in which he differs from Chamberlin. Another place where he presents his modified views of the planetesimal hypothesis is in the book entitled "The Evolution of the Earth and its Inhabitants," 1918, to which he contributed the first chapter.

Paleontology and Evolution.

Since the days at Lehigh when Barrell taught zoology as well as geology, he had remained deeply interested in the more fundamental problems of paleontology and zoology. He never was much concerned with species and genera, however, or with classification, but rather with the bony mechanism of vertebrates, evolution, and the environmental causes that bring about the sweeping changes in organisms.

Through the determining of ancient climates as discerned in the nature of the geologic formations, and more especially in the continental deposits of the Silurian and Devonian, Barrell's interest was directed to an hypothesis first set forth by Chamberlin, as to the first habitats of fishes and the origin of lungs and limbs in dipnoans and amphibians. His ideas on these subjects culminated in 1916 in his "Influence of Silurian-Devonian Climates on the Rise of Air-breathing Vertebrates." The problems he seeks to answer are two: "first, as to the environment in which fishes develop; second, the changes in the environment and the associated organic responses which brought forth amphibians from fishes. It is the

solution of the second problem which is here especially sought.''

''It is shown to be probable that fishes arose in land waters. As such they constituted primarily a river fauna.'' It is in the Middle Devonian that ''the fishes first really begin to conquer the ocean and its former rulers.'' On the other hand, in the fresh waters of this time fishes abounded in greater variety than in the seas. In the Upper Devonian, crossopterygian fishes had risen to a dominant place, and they were adapted to live in warm climates marked by alternation of wet and dry seasons. It was this environment that gave rise to the amphibians. ''The warm and stagnant waters of the dry season compelled those fishes which should survive to make larger and larger use of air.''

''The evidence is regarded as strong that the air-bladder was originally developed as a supplemental breathing organ, although in modern fishes it has been mostly diverted to other uses.'' Barrell also quotes this significant passage from W. D. Matthew: ''The evolution of land life in adaptation to recurrent periods of aridity supplies a satisfactory background of cause for the whole evolution of the higher vertebrates.'' And he adds: ''The rise of amphibians from river fishes in an epoch of semiaridity was one of the major steps in the evolution of man.'' ''Climatic oscillation is a major ulterior factor in evolution.''

The study of the natural environment as recorded in the sediments that also entombed the fossils led naturally to the work entitled ''Probable Relations of Climatic Change to the Origin of the Tertiary Ape-Man.'' Here we again read that climatic variation is for terrestrial life its most fundamental evolutionary factor. And this was especially true for the Pleistocene, when the land biotas ''have come and gone at the command of climatic change. Those animals which were trapped on the northern sides of mountain ranges or water barriers were remorselessly exterminated by the waves of advancing cold; those which could escape to the south returned with milder climates, but changed in their assemblage.'' Barrell held that man was brought to his present high physical and mental state not as the ''mere product of time and life,'' but that he is ''peculiarly a child of the earth and is born of her

vicissitudes.'' ''The progress of life on the earth has been highly favored, consequently, by the rhythmic pulses of diastrophic and climatic changes which have remorselessly urged forward the troop of living creatures. The progress of organic evolution has depended on a series of fortunate physical events, conditioned in the internal nature of sun and earth, rather than the by-product of mere life activities as expressed in orthogenesis through long periods of time. Organic evolution is in no sense an inevitable consequence of life, and the compulsion of climatic change has been more than once a fundamental factor in the age-long ascent from protozoan to man.''

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The Lower Cambrian of the southern Appalachians.

Piedmont terraces.

Description of the Housatonic quadrangle.

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